IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of

HUANZHAO ZENG
and KEVIN R. HUDSON

HP Docket No. 10012661-1

Serial No.	:	10/004,009	Examiner B. Menberu
Filed	:	October 29, 2001	Group Art Unit 2626
For	:	METHOD AND SYSTEM FOR MANAGEMENT OF COLOR THROUGH CONVERSION BETWEEN COLOR SPACES	

Commissioner for Patents
P. O. Box 1450
Alexandria, Virginia 22313-1450

Sir:

DECLARATION UNDER § 1.131

We declare as follows:

1. We are inventors who, on October 29, 2001, filed the above-identified application. At the time of such invention, we were employees of Hewlett-Packard Company.

2. Prior to August 30, 2001, the effective date of the application from which US Pub. No. US 2002/0027603 A1 published, we conceived of our invention, and diligently worked toward reducing our invention to practice. Such conception, and diligent reduction to practice from a time preceding August 30, 2001, is demonstrated by the HP Invention Disclosure, dated February 21, 2001, which is attached to this declaration as Exhibit 1. As indicated on page 1 of the HP Invention Disclosure (Exhibit 1), the invention was actually built or tested in July 2000.

3. Prior to December 15, 2000, the effective date of the application from which US Pub. No. US 2002/0075491 A1 published, we conceived of our invention,

and diligently worked toward reducing our invention to practice. Such conception, and diligent reduction to practice from a time preceding December 15, 2000, is demonstrated by the HP Invention Disclosure attached to this declaration as Exhibit 1. As indicated on page 1 of the HP Invention Disclosure (Exhibit 1), the invention was actually built or tested in July 2000.

4. At the time of preparing Exhibit 1, which preceded both August 30, 2001 (the effective date of US Pub. No. US 2002/0027603 A1 to Kuwata et al.) and December 15, 2000 (the effective date of US Pub. No. US 2002/0075491 A1 to Bares et al.), we had conceived of a method of mapping a color in a color image produced by an image device from a presentation color space to a destination color space, the method comprising the steps of: receiving the color from the image device; determining whether the received color is to be preserved; converting the received color from the presentation color space to the destination color space using a default profile if it is determined that the received color is to be preserved; and converting the received color from the presentation color space to the destination color space using a device-specific profile absent a determination that the received color is to be preserved.

5. At the time of preparing Exhibit 1, which preceded both August 30, 2001 (the effective date of Kuwata et al.) and December 15, 2000 (the effective date of Bares et al.), we also had conceived of a method of mapping an initial-formatted color produced by an image device in a presentation color space to a destination color space comprising the steps of: receiving the initial-formatted color from the image device; converting the initial-formatted color from the presentation color

space to the destination color space using a device-specific profile to produce a device-formatted color; converting the initial-formatted color from the presentation color space to the destination color space using a default profile to produce a default-formatted color, the default profile being adapted to preserve primary colors of the presentation color space; and producing a resultant color in the destination color space by weighted combination of the device-formatted color with the default-formatted color.

6. At the time of preparing Exhibit 1, which preceded both August 30, 2001 (the effective date of Kuwata et al.) and December 15, 2000 (the effective date of Bares et al.), we also had conceived of a storage medium readable by a computer, having embodied therein a program of instructions executable by the computer to perform the steps of: receiving a color in a presentation color space from an image device; determining whether the received color is to be preserved; converting the received color to a destination color space using a default profile if it is determined that the received color is to be preserved; and converting the received color to the destination color space using a device-specific profile absent a determination that the received color is to be preserved.

7. At the time of preparing Exhibit 1, which preceded both August 30, 2001 (the effective date of Kuwata et al.) and December 15, 2000 (the effective date of Bares et al.), we also had conceived of a storage medium readable by a computer, having embodied therein a program of instructions executable by the computer to perform the steps of: receiving an initial-formatted color in a presentation color space from an image device; converting the initial-format color from the presentation color space to a destination color space using a device-

specific profile to produce a device-formatted color; converting the initial-formatted color from the presentation color space to the destination color space using a default profile to produce a default-formatted color, the default profile being adapted to preserve primary colors of the presentation color space; and producing a resultant color in the destination color space by weighted combination of the device-formatted color with the default-formatted color.

8. At the time of preparing Exhibit 1, which preceded both August 30, 2001 (the effective date of Kuwata et al.) and December 15, 2000 (the effective date of Bares et al.), we also had conceived of a method of mapping a source image from a presentation color space to a printing color space comprising the steps of: receiving the source image, the source image including colors defined in the presentation color space; converting the source image from the presentation color space to an intermediate color space in accordance with a conversion function which accommodates preservation of one or more colors to produce a color-preserved image; converting the color-preserved image back from the intermediate color space to the presentation color space to produce a color-preserved image in the presentation color space; and converting the color-preserved image from the presentation color space to the printing color space.

9. At the time of preparing Exhibit 1, which preceded both August 30, 2001 (the effective date of Kuwata et al.) and December 15, 2000 (the effective date of Bares et al.), we also had conceived of a storage medium readable by a computer, having embodied therein a program of instructions executable by the computer to perform the steps of: receiving a source image including colors defined in the presentation color space; converting the source image from the presentation

color space to an intermediate color space in accordance with a conversion function which accommodates preservation of one or more colors to produce a color-preserved image; converting the color-preserved image back from the intermediate color space to the presentation color space to produce a color-preserved image in the presentation color space; and converting the color-preserved image from the presentation color space to the printing color space.

10. At the time of preparing Exhibit 1, which preceded both August 30, 2001 (the effective date of Kuwata et al.) and December 15, 2000 (the effective date of Bares et al.), we also had conceived of a color management system comprising: an image device configured to present an initial-formatted color image defined in a presentation color space; a print processor configured to receive the initial-formatted color image from the image device, to convert the initial-formatted color image from the presentation color space to a destination color space using a device-specific profile to produce a device-formatted color image, to convert the initial-formatted color image from the presentation color space to the destination color space using a default profile to produce a default-formatted color image the default profile being adapted to preserve primary colors of the presentation color space, to produce a resultant color image in the destination color space with primary colors derived using the default profile and non-primary colors derived using the device-specific profile by weighted combination of the device-formatted color image with the default-formatted color image, to convert the resultant color image from the destination color space to the presentation color space to produce a color-preserved color image in the presentation color space, and to convert the color-preserved color image from the presentation color space to a printing color space; and a print

engine configured to print the color-preserved color image in the printing color space.

11. Following our conception, we diligently worked toward reducing our inventions to practice, and in July 2000 actually reduced our invention to practice. On October 29, 2001, we filed the present patent application.

12. All acts set forth herein and/or relied upon for the purpose of establishing invention prior to December 15, 2001 were carried out in the United States.

13. We declare that all statements made herein of our knowledge are true and all statements made on information and belief are believed to be true. These statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both under § 1001 of Title 18 of the United States Code. We understand that such willful false statements may jeopardize the validity of the application or any patent issuing therefrom.

Date: 8/25/2005 Huanzhao Zeng

Date: 26 Aug 2005 Kevin R. Hudson

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INVENTION DISCLOSURE			PAGE ONE OF 3
PDNO 10012661	DATE RCVD 2/21/01	IPD	ATTORNEY EAA

Instructions: The information contained in this document is ***COMPANY CONFIDENTIAL*** *and may not be disclosed to others without prior authorization. Submit this disclosure to the HP Legal Department as soon as possible. No patent protection is possible until a patent application is authorized, prepared, and submitted to the Government.*

Descriptive Title of Invention:
A Method to Convert a RGB 3-D Lookup Table into a Printer ICC Profile

Name of Project:

Product Name or Number:

[redacted]

Was a product including the invention announced, offered for sale, sold, or is such activity proposed? If so, the date(s) and location(s):
No.

Was the invention disclosed to anyone outside of HP, or will such disclosure occur? If so, the date(s) and name(s):
No.

If any of the above situations will occur within 3 months, call your IP attorney or the Legal Department now at 1-898-4919 or 970-898-4919

Was the invention described in a lab book or other record? If so, please identify (lab book #, etc.)

Yes. It was emailed to HP Color Rendering Forum about five months ago.

Was the invention built or tested? If so, the date:

Yes. July 2000.

Was this invention made under a government contract? If so, the agency and contract number:

No.

Description of Invention: *Please preserve all records of the invention and attach additional pages for the following. Each additional page should be signed and dated by the inventor(s) and witness(es).*

A. Description of the construction and operation of the invention (include appropriate schematic, block, & timing diagrams; drawings; samples; graphs; flowcharts; computer listings; test results; etc.)
B. Advantages of the invention over what has been done before.
C. Problems solved by the invention.
D. Prior solutions and their disadvantages (if available, attach copies of product literature, technical articles, patents, etc.).

Signature of Inventor(s): Pursuant to my (our) employment agreement, I (we) submit this disclosure on this date: [2/20/2001].

Employee No.	Name	Signature	Telnet	Mailstop	Entity & Lab Name
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Employee No.	Name	Signature	Telnet	Mailstop	Entity & Lab Name
Employee No.	Name	Signature	Telnet	Mailstop	Entity & Lab Name

(If more than four inventors, include additional information on another copy of this form and attach to this document)

Company Confidential

EXHIBIT 1

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INVENTION DISCLOSURE COMPANY CONFIDENTIAL

Signature of Witness(es): *(Please try to obtain the signature of the person(s) to whom invention was first disclosed)*

The invention was first explained to, and understood by, me (us) on this date: [ ]

Full Name	Signature	Date of Signature
DONGLI YANG	Dongyang	2/20/2001
KEVIN R. HUDSON	Kevin R Hudson	20 FEB '01

Inventor & Home Address Information: *(If more than four inventors, include addl information on a copy of this form & attach to this document)*

Inventor's Full Name
Huanzhao Zeng

[redacted]

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Inventor's Full Name

Street

City State Zip

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Description of Invention: *Please preserve all records of the invention and attach additional pages for the following. Each additional page should be signed and dated by the inventor(s) and witness(es).*

A. Description of the construction and operation of the invention (include appropriate schematic, block, & timing diagrams; drawings; samples; graphs; flowcharts; computer listings; test results; etc.)

This is a method to convert a closed-loop sRGB lookup table (LUT) that is used in a closed-loop workflow into a printer ICC profile for open color architecture. CIE XYZ color space is used as ICC profile's connection space. To construct a BToA0 tag, a matrix to convert CIE XYZ values into linear sRGB is converted into the matrix portion of the BToA0 tag, TRC curves to convert linear sRGB into nonlinear sRGB are put into the input 1-D LUTs of the BToA0 tag, the closed-loop sRGB LUT is put into the multi-dimensional LUT of the BToA0 tag, and the output 1-D LUTs are set to identity curves. The AToB0 tag is linear interpolated from the measurement data. Applying printer ICC profiles created by this method to an ICC workflow and set the input ICC profile as sRGB ICC profile, it transforms colors almost the same as that using a closed-loop workflow. This guarantees the color consistency between using a closed-loop workflow and an ICC workflow. It also solve the saturation rendering intent problem existed in generic ICC profiles.

B. Advantages of the invention over what has been done before.

This invention provides a solution to optimuze gamut mapping and to guarantee primary mapping. A printer ICC profile created by this method is optimized for a specific input RGB color space. Because of this optimization, the color map is superior to color maps using ICC profiles created by prio methods. It also guarantees that input RGB primary colors map to printer device primary colors if needed. ICC profiles created by this method also guarantees color transformations by an ICC workflow is almost the same as by using a closed-loop workflow.

C. Problems solved by the invention.

1. This invention provides a method to convert a closed-loop lookup table into a printer ICC profile accurately
2. It provides a method to create special printer ICC profiles that are optimized for a monitor RGB color space.
3. It provides a method to map input primary colors into printer primary colors using ICC workflow. This is very important for the color mapping for graphic objects.
4. It provides a method to consistently transform colors from a monitor RGB color space into a printer device color space using a closed-loop workflow and an ICC workflow

D. Prior solutions and their disadvantages (if available, attach copies of product literature, technical articles, patents, etc.).

1. In order to map a monitor's primary colors into a printer's primary colors, a prior solution is to use a closed-loop lookup table in a closed-loop workflow Prior ICC approach cannot achieve primary mapping. The disavantage is that the closed-loop table cannot be used to an ICC workflow.
2. Printer ICC profiles created by prior solutions are not able to map monitor RGB primary colors into printer primary colors.
3. The color consistency between using a closed-loop workflow and an ICC workflow cannot be achieved by prior solutions
4. The gamut mapping cannot be optimized because printer ICC profiles created by prior methods are for generic application. This limits the color transformation quality.

Primary Preservation in ICC Color Management System

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Abstract

International Color Concorsium (ICC) defined four rendering intents for ICC color management system. One of the four, the saturation rendering intent, has never been practiced successfully. The reason is that most users expect to have primary matching for this intent, but the current ICC workflow makes this impossible. In this paper, three approaches to achieve primary matching for printing applications will be presented. Two of the primary matching approaches are applied to RGB to CMYK transformation. We start with building a printer ICC profile that converts default monitor RGB primaries to corresponding printer primaries. If a source monitor RGB color space is different from the default RGB color space, the default RGB color space is applied for the saturation rendering intent for primary preservation. The reason of doing it this way is that the primary matching is more important than color accuracy for printing objects(such as drawing and text objects) in which the saturation intent is applied, and that different source monitor RGB color spaces are not very different. For more accurate color transformation but still to preserve the primary matching, the source monitor RGB color space is adjusted so that the primaries are fully adapted to those of the default RGB color space and the adaptation is decreased gradually as the hue of a source color moves off primaries. Since both the source primaries and the destination primaries are known as gamut mapping is performed in a smart CMM environment, the primary matching can be achieved by hue rotation and gamut adaptation during the real-time linking. The method of primary matching in a smart CMM can be applied to any source device RGB and CMYK color spaces, therefore it is more general than the other two methods.

1. Introduction

There are many approaches to reproduce reliable and desirable colors as colors are transformed across a color processing system. One intuitive approach is to fix a source device and a destination device and to calibrate the system for the color transformation from the source color space to the destination color space. This kind of color processing system is called a closed-loop system. Because both the source primary hues and destination primary hues are known in the color calibration step, a color transformation lookup table can be created in a way that each input primary is mapped to the corresponding output primary.

Although a closed-loop system is easy to calibrate, it is problematic as the world moves to network oriented open architecture. As an open system comprises unknown number of source and destination color devices, a closed-loop approach is not capable of calibrating the system. If all device-dependent colors from different color devices are converted into a device-independent color space, it will be easier to maintain color specifications for each device. A color management system based on a well-defined color system, such as CIE color spaces, as a connection bridge meets the requirement for network based color imaging systems. This kind of color management system and components was standardized by the International Color Consortium (ICC)[1]. The ICC profile format, which was evolved from the ColorSync 2.0 format, is served as a cross-platform device profile format for color device characterizations.

The profile connection space (PCS) is the heart of the ICC color management, which is CIE XYZ or CIE L*a*b* in D50 illuminant with other specified viewing conditions. The color transformation using the ICC color management is based on the Profile-PCS-Profile model. Any device color is communicated with other device colors through the PCS. In the current ICC workflow, a source color is converted to a color in the PCS and then converted to the destination color space. The information of the source primaries is not passed through the PCS, thus hue adjustment cannot be performed so that the source primaries match the destination primaries. Because of the hue mismatch problem, it limits the application of ICC color

management system. For example, to print a Microsoft PowerPoint document to an inkjet printer, the primary match is usually required, especially for pure yellow. A standard ICC color management cannot achieve primary matching.

To solve the primary mismatch problem, we developed several approaches to guarantee that the source primaries match the corresponding destination primaries in ICC color management system. In the following section, the primary mismatch problem existed in the current color management system will be briefly described. Two primary matching approaches for RGB to CMYK transformation will be described in the section 3. A more general primary matching approach will be described in the section 4. The last section is the conclusion remark.

2. Standard Color Management Workflow

The Profile-PCS-Profile model in a standard ICC color management workflow is shown in Fig. 1 for the color transform from the source color space to the destination color space. A CMM (color management module) takes an AToBi tag (a table for the conversion from the source device to PCS) from the source ICC profile and a BToAi tag (a table for the conversion from PCS to the destination device color space) from the destination ICC profile to create a color link for color transform. The BToAi tag is a table (it includes a matrix, 1-D LUTs, and a multi-dimensional LUT) created by gamut mapping, GCR, and so on. While this tag is created, the profile creator does not know the primaries of the source color space thus the primary matching from the source color space to the destination color space is not guaranteed. Even if the destination profile is adjusted to achieve the primary matching for a specific source color space to the destination color space, the primary matching is destroyed if the source color space is changed.

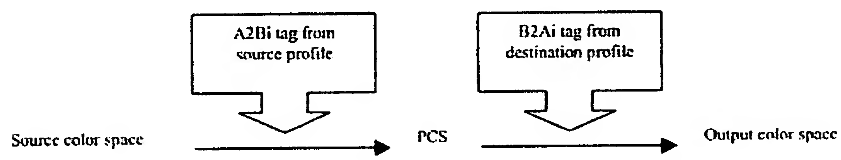

Fig. 1 Color transformation in the current ICC color management system

An example of the color transformation from different monitor RGB color spaces to a printer color space is shown in Fig. 2. Different source ICC profiles are applied for different source color space. Because the printer ICC profile is created without the knowledge of the definition of the source color space, the primaries of a source color space is not guaranteed to match the corresponding printer primaries.

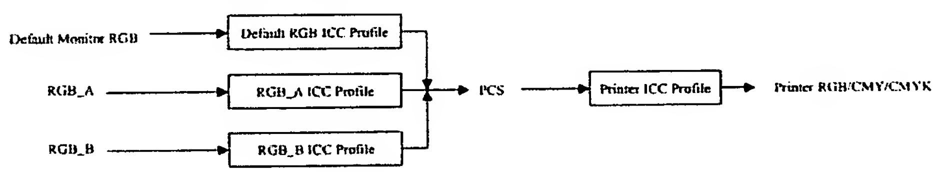

Fig. 2 An example of color transformation from different monitor RGB color spaces to a printer color space by a standard ICC color management

3. Achieving Primary Matching for Monitor RGB to Printer CMYK Transformation in ICC Color Management System

Primary matching for RGB to CMYK transformation is very important in printing documents in office environments, such as for printing Microsoft Word documents and Microsoft PowerPoint documents. By using ICC color management for color transformation, we can specify the saturation rendering for printing

documents that require primary matching. However, primary matching must be achieved for the saturation rendering intent. Primary matching for the transformation from RGB color spaces to a printer RGB, CMY, or CMYK color space is guaranteed by the following processes:

a) To create a printer ICC profile that guarantees primary matching in the saturation rendering intent for the conversion from a specific monitor RGB color space (default RGB color space) to a printer RGB or CMYK color space;
b) If the source monitor RGB color space is different from the default RGB color space and primary matching is requested (e.g. for the saturation rendering intent), one of the following processes is performed:
    - the source monitor RGB color space is substituted by the default RGB color space; or
    - the source monitor RGB color space is adjusted so that the primaries are fully adapted to the default RGB color space and the adaptation is decreased gradually as the hue of a source color moves off primaries.

3.1 Creating a Printer ICC Profile for Primary Matching between Monitor Primaries and Corresponding Printer Primaries

The procedures to create a printer ICC profile for primary matching include three steps. First a decision must be made for a default source monitor RGB color space. sRGB is often selected as the default monitor RGB color space[2].

The second step is to construct a 3-D lookup table (LUT) for the color conversion from the default RGB color space to the printer output color space (RGB, CMY, or CMYK). This LUT is constructed in a way that the input primaries match the output primaries. For printing drawing and text objects (or for the saturation rendering intent), it may require the matching of cyan (C), magenta (M), and yellow (Y) primaries. In some cases, the primary matching of all three primaries is not required. However, the primary matching for pure yellow is usually required for inkjet printing. The next important primary for primary matching is magenta.

The third step is to convert this 3-D LUT into the BToA2 tag (the LUT for the conversion from the PCS to the printer device color space for the saturation rendering intent) of a printer ICC profile. CIE XYZ color space is selected as the profile connection space (PCS)[3]. To construct BToA2 tag using CIE XYZ as PCS, the inverse gamma curve of the default color space (e.g sRGB) is put into the input 1-D LUT of the BToA2 tag, the matrix for the conversion from CIE XYZ to the default color space (e.g. sRGB) is put into the matrix data of the BToA2 tag, and the closed-loop LUT is linearly interpolated and scaled to store in the BToAi tag's 3-D LUT.

3.2 Modifying a Color Management Module (CMM) to Guarantee the Primary Matching for Different Input Monitor RGB Color Space

A printer ICC profile created by the approach described in the section 3.1 only achieves the primary matching between the default monitor RGB color space and the output printer color space. For an input RGB color space different from the default RGB color space, a standard CMM applies the corresponding source RGB ICC profile other than the default RGB ICC profile. Thus the primary matching is destroyed. In most of office printing environments, such as in printing Microsoft Word and PowerPoint documents, the primary matching is usually more important than color accuracy. Therefore, we can force a CMM to select the default RGB ICC profile in the saturation rendering intent for primary matching. A block diagram to achieve primary matching by this approach is shown in Fig. 3. The printer ICC profile used in this system is created by the method described in the section 3.1. If primary matching is required (i.e. the saturation intent is selected), the default input RGB ICC profile is applied for any input monitor RGB color space. If primary matching is not required, the corresponding source RGB color space is applied. Because the characteristics of different monitor RGB color spaces are similar with each other, this does not make unacceptable results for printing documents in which primary matching is more important than color accuracy.

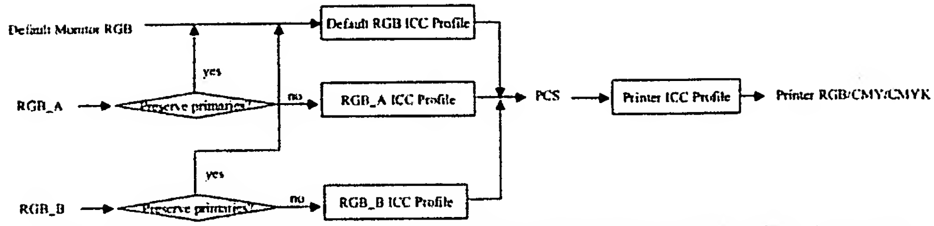

Fig. 3 A system for primary matching in printing objects described in moonitor RGB color spaces

For more accurate color transformation but still preserving the primary matching, the combination of both the current source monitor RGB ICC profile and the default monitor RGB ICC profile are used in the linking step. Fig.4 shows six primaries (red, green, blue, cyan, magenta, and yellow) in a typical 2-D color space. If the hue of a source color is exactly in the hue angle of a primary, the default RGB ICC profile is applied for the color transformation from the source color space to the PCS during the linking step. If the hue of a source color is off any primary, the weighting combination of both ICC profiles is applied for the color transformation from the input color space to PCS during the linking step. The mathematical representations are shown in Eqs. 1 to 3.

$$[XYZ]_d = f_d(RGB) \tag{1}$$
$$[XYZ]_i = f_i(RGB) \tag{2}$$
$$[XYZ] = c \cdot [XYZ]_i + (1-c) \cdot [XYZ]_d \tag{3}$$

where $f_d(RGB)$ is a function for the conversion from RGB to CIE XYZ using the default monitor ICC profile, $f_i(RGB)$ is a function for the conversion from RGB to CIE XYZ using the current set of the monitor ICC profile. c is a weighting parameter, and [XYZ] is the final CIE XYZ value.

The weighting parameter c is a function of the hue angle of a source color. If the hue angle of a source color is overlapped with a primary, $c = 0$ and only the default ICC profile is applied. If the hue is far off any primary, $c = 1$ and only the ICC profile that represents the current source RGB color space is applied. A block diagram representing this approach is shown in Fig. 5.

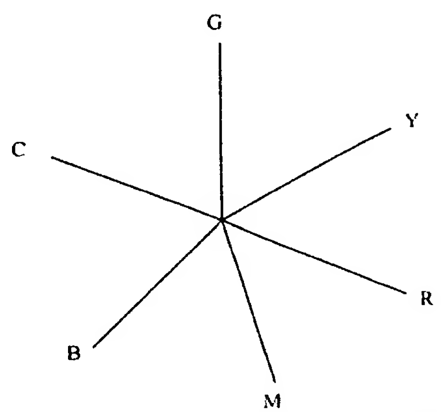

Fig. 4 Six monitor primaries in a 2-D color space

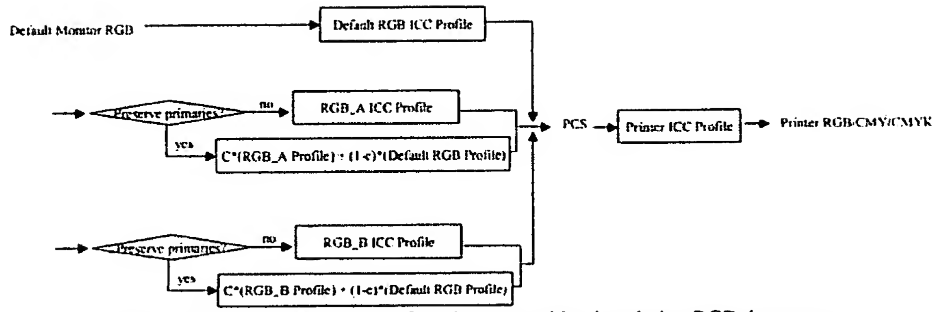

Fig. 5 A more accurate approach for primary matching in printing RGB documents

4. Primary Preservation in a Smart CMM

The core functionalities of current CMMs are to link a set of ICC profiles and to perform color transformation from one color space to another. Because gamut mapping is a slow process and there is no sufficiently robust gamut mapping algorithms for general purposes, the gamut mapping is not performed in a CMM. The ICC (and Postscript) solution is to perform gamut mapping in the step of ICC profile (or CRD) creation. Because the source gamut (device gamut or image gamut) is unknown while the gamut mapping is performed, gamut mapping cannot be optimized[4] and primary preservation cannot be achieved. This degrades the color transformation quality in some applications.

A smart CMM[3, 5, 6] does gamut mapping at the linking step, thus both the source/destination primaries and the source/destination gamuts are known in the gamut mapping step. This makes it possible to achieve primary matching through hue rotation and gamut adaptation (to adapt the source gamut to the destination gamut). A color transformation with the compromise of the perceptual mapping for photographic images and the primary matching for presentation documents is easier to achieve in a smart CMM than in a dumb CMM. The difference of this approach from the approach described in the previous section is that the gamut mapping is processed in the smart CMM at real-time instead of being processed off-time, and the source color space instead of a default RGB color space is used for the gamut mapping. This method works for both RGB type and CMYK type source color spaces for primary preservation in a printing system.

5. Conclusions

Different approaches for primary preservation in ICC color management have been described. The simplest approach for the primary preservation for printing objects described by monitor RGB color spaces is to construct a printer ICC profile that guarantees the primaries of the default input monitor RGB color space matching the corresponding printer's primaries, and to use the default monitor RGB ICC profile in the saturation rendering intent so that primary colors of any monitor RGB color space match primary colors of the printer color space. Another approach to achieve primary matching with higher color accuracy is to apply both the default RGB ICC profile and the ICC profile represented the current source monitor RGB color space by a weighting function. If a source color is a primary color and primary preservation is required, the weight for the default RGB color space is set to 100% and the the weight for the current source RGB color space is set to 0%. If a color is far off a primary, the weight for the default RGB color space is set to 0% and the the weight for the current source RGB color space is set to 100%. Weights derived from these two cases are used for in-between colors.

Above approaches are used in a dumb CMM and works for source monitor RGB color spaces only. In a smart CMM environment, hue rotation and gamut adaptation are used in the gamut mapping at real-time to adapt the source primaries to the destination primaries. This approach works for the primary preservation for both RGB and CMYK printing. Becauc both the source and the destination gamuts are known, it is possible to make a linking table that works fairly good for both the perceptual rendering intent for

photographic images and the saturation rendering intent for presentation documents. This is very useful for printing documents that mix photographic images with drawing and text objects.

References:

1. Specification ICC.1:1998-09, International Color Consortium, http://www.color.org
2. IEC/3WD 61966-2.1: Colour measurement and management in multimedia systems and equipment – Part 2.1: Default RGB colour space – sRGB.
3. H. Zeng, "Color Transformation Accuracy and Efficiency in ICC Color Management", Proc. IS&T/SID 9th Color Imaging Conf., (2001).
4. J. Morovic and M. Luo, "The Fundamentals of Gamut Mapping: a Survey", J. Imaging Sci. Technol. 45, 283-290 (2001).
5. T. Newman, J. Haikin, and T. Kohler, "Supporting Both Preferred and Predictable Reproduction with ICC Profiles", Proc. IS&T/SID 8th Color Imaging Conf., 65-69 (2000).
6. T. Kohler, "The Next Generation of Color Management System", Proc. IS&T/SID 8th Color Imaging Conf., 61-64 (2000).

Primary Preservation for the Transformation from Monitor RGB Color Spaces to a RGB or CMYK Printer Color Space in Color Management System

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1. Introduction

There are many approaches to reproduce reliable and desirable colors as colors are transformed across a color processing system. One intuitive approach is to fix an input device and an output device and to calibrate the system for the color transformation from the input color space to the output color space. This kind of color processing system is called a closed-loop system. Because both input and output primary hues are known in the color calibration step, a color transformation lookup table can be created in a way that each input primary is mapped to the corresponding output primary.

Although a closed-loop system is easy to calibrate, it is problematic as the world moves to network oriented open architecture. As an open system comprises unknown number of input and output color devices, a closed-loop approach is not capable of calibrating the system. If all device-dependent colors from different color devices are converted into a device-independent color space, it will be easier to maintain color specifications of different devices. A color management system based on a well-defined color system, such as CIE color spaces, as a connection bridge meets the requirement for network based color imaging systems. This kind of color management system and components was standardized by the International Color Consortium (ICC)[1,2]. The ICC profile format, which was evolved from the ColorSync 2.0 format, is served as a cross-platform device profile format for color device characterizations.

The profile connection space (PCS) is the heart of the ICC color management, which is CIE XYZ or CIE L*a*b* in D50 illuminant with other specified viewing conditions. The color transformation using the ICC color management is based on the Profile-PCS-Profile model. Any device color is communicated with other device colors through the PCS. In the current ICC workflow, an input color is converted to a color in PCS and then converted to the output color space. The information of the primaries of the input color space is not passed through the PCS, thus hue adjustment cannot be performed so that the input primaries match the ouput primaries. Because of this kind of hue mismatch problem, it limits the application of ICC color management system. For example, to print a Microsoft PowerPoint document to an inkjet printer, the primary match is usually required, especially for pure yellow. A standard ICC color management cannot guarantee primary match.

To solve this problem, a method and system was developed to guarantee that input monitor RGB primaries match printer output primaries in ICC color management system.

2. Standard Color Management Workflow

The Profile-PCS-Profile model in a standard ICC color management workflow is shown in Fig. 1 for the forward transform. A CMM (color management module) takes an AToBi tag (a table for input device to PCS conversion) from the first ICC profile and a BToAi tag (a table for PCS to output device color space conversion) from the second ICC profile to create a color link for color transform. The BToAi tag is a table (may includes a matrix, 1-D LUTs, and a multi-dimensional LUT) generated by gamut mapping, GCR, and so on. When this tag is created, the profile creator does not know the primaries of the input color space thus the primary matching from the input color space to the output color space is not guaranteed. Even if

the profile B is adjusted so that the primaries of the input color space match the primaries of the output color space, the primary matching is destroyed if the input color space is changed.

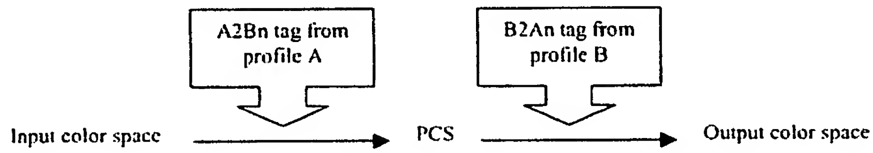

Fig. 1 Forward color transformation in the current ICC color management

The color transformation of three monitor RGB color spaces to a printer color space is shown in Fig. A of the Apendix. Different input ICC profiles are applied for different input color space.

3. A Method to Achieve Primary Matching in ICC Color Management System

This invention includes following processes for the conversion from monitor RGB color spaces to a printer RGB or CMYK color space to achieve primary matching.

1. An approach to create a printer ICC profile that guarantees primary matching for the conversion from a specific monitor RGB color space (default RGB color space) to a printer RGB or CMYK color space;
2. If the input monitor RGB color space is different from the default RGB color space and primary matching is requested (e.g. for the saturation rendering intent), one of the following processes is performed:
   - the input monitor RGB color space is substituted by the default RGB color space; or
   - the input monitor RGB color space is adjusted in a way that the primaries are fully adapted to the default RGB color space and the adaptation is decreased gradually as the hue of an input color moves out of primaries.

The details for creating a printer ICC profile are described in the section 4, and the details of primary matching for different input monitor RGB color spaces are described in the section 5.

4. Creating a Printer ICC Profile for Primary Matching between a Monitor's Primaries and the Printer's Primaries

First a decision is made for a default input monitor RGB color space. sRGB is often selected as the default monitor RGB color space[3]. The second step is to construct a 3-D lookup table (LUT) for the color conversion from the input RGB color space to the printer output color space (RGB, CMY, or CMYK). This LUT is constructed in a way that the input primaries match the output primaries. For printing presentation documents (or for the saturation rendering intent), it may require the matching of six primaries, R (red), G (green), blue (B), cyan (C), magenta (M), and yellow (Y). In some cases, the primary matching of all six primaries is not required. However, the primary matching for pure yellow is usually required for inkjet printing. The next important primary for primary matching is magenta.

The third step is to convert this 3-D LUT into the B2Ai (i = 0, 1, or 2) tag of a printer ICC profile. CIE XYZ color space is selected as the profile connection space (PCS). To construct BToAi tag using CIE XYZ as PCS, the inverse gamma curve of default color space (e.g sRGB) is put into the input 1-D LUT of the BToAi tag, the matrix for the conversion from CIE XYZ to the default color space (e.g. sRGB) is put into the matrix data of the BToAi tag, and the closed-loop LUT is linearly interpolated and scaled to store in the BToAi tag's 3-D LUT.

5. Modify a Color Management Module (CMM) to Guarantee the Primary Matching for Different Input Monitor RGB Color Space

A printer ICC profile created by the approach described in the section 4 only achieves the primary matching between the default monitor RGB color space and the output printer color space. For an input RGB color space other than the default RGB color space, a CMM applies the corresponding input RGB ICC profile other than the default RGB ICC profile. The result is that the primary matching is destroyed. For printing presentation documents, the primary matching is usually more important than color accuracy. Therefore, we can foce a CMM to select the default RGB ICC profile in the saturation rendering intent so that the primary matching can be preserved. A block diagram is shown in Fig. B of the Apendix. If primary matching is required, the default input RGB ICC profile is applied for any input monitor RGB color space. Otherwise, the corresponding input RGB color space is applied. The printer ICC profile is created by the apporach described in the section 4.

For more accurate color reproduction but still preserve the primary matching, the combination of both the current input monitor RGB ICC profile and the default monitor RGB ICC profile are used in the linking step. Fig.2 shows six primaries in a typical 2-D color space. If the hue of an input color is in the hue angle of a primary, the default RGB ICC profile is applied for the color transformation from the input color space to PCS during the linking step. If the hue of an input color is off any primary, the weighting combination of both ICC profiles is applied for the color transformation from the input color space to PCS during the linking step. The mathematical representations are shown in Eq (1-3).

$$[XYZ]_d = f_d(RGB) \quad (1)$$
$$[XYZ]_i = f_i(RGB) \quad (2)$$
$$[XYZ] = c \cdot [XYZ]_i + (1-c) \cdot [XYZ]_d \quad (3)$$

where $f_d(RGB)$ is the converion from RGB to CIE XYZ using default monitor ICC profile, $f_i(RGB)$ is the conversion from RGB to CIE XYZ using an ICC profile other than the default ICC profile, c is a weighting parameter, and [XYZ] is the final CIE XYZ value.

The weighting parameter c is a function of the hue angle of an input color. If the hue angle is overlapped with a primary, $c = 0$ and only the default ICC profile is applied. If the hue is far off any primary, $c = 1$ and only the ICC profile that represents the current input RGB color space is applied.

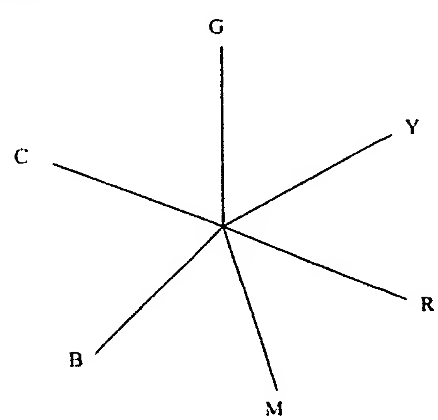

Fig. 2 Six monitor primaries in a 2-D color space

A block diagram for this approach is shown in Fig. C of the appendix.

6. Claims of the Invention

1. A method to construct a printer ICC profile that guarantees the primaries of a specific input monitor RGB color space match corresponding printer's primaries;
2. Using a default RGB ICC profile in the saturation rendering intent so that primary colors of any monitor RGB color space match primary colors of the printer color space;
3. Another method to achieve primary matching by applying the combination of the default RGB ICC profile and the ICC profile that defines the current input monitor RGB color space.
4. Applying claim 2 or 3 to create a linking profile for the saturation rendering intent in a color management module, depending on the quality requirement (for high color accuracy, applying claim 3; otherwise applying chaim2);
5. Applying a printer ICC profile created by claim 1 and a method described in claim 2 or 3 for the saturation rendering intent for printing documents that require primary matching.

References:

1. Specification ICC.1:1998-09, International Color Consortium, http://www.color.org
2. Document ICC.1A:1999-04, International Color Consortium, http://www.color.org
3. IEC/3WD 61966-2.1: Colour measurement and management in multimedia systems and equipment – Part 2.1: Default RGB colour space – sRGB.